



R.C.A. INSTITUTES. INC. *formerly-* MARCONI INSTITUTE *Founded 1909*



Technical Lesson 15

CAPACITY

What is capacity? Under what other names does it appear and where and why is it used? Capacity is the ability to receive, contain and store up energy. For example, a tank has the ability of storing water, oil and other forms of liquid. A condenser, in the electrical sense, stores electricity. It is used in power line transmission as well as in radio. Capacitance is another word used to describe capacity and this term is used considerably when reference is made to the electrostatic capacity of a device. As capacity plays a large part in many ways and in various phases of the radio industry it may be well for you to know how simple it is to construct a device possessing capacity or capacitance. If you secure a piece of glass and two sheets



Figure 1



Figure 3

of tinfoil you have the elements of a very simple condenser. Figures 1 and 2 indicate how this condenser is assembled. A large number of commercial condensers used with spark coils are usually made of tinfoil and paraffined paper, the tinfoil being the conductors and the paper the insulator or dielectric, as it is called. Alternate layers of tinfoil and paper make up the condenser. A paraffined paper condenser with leads is shown in Figure 3.

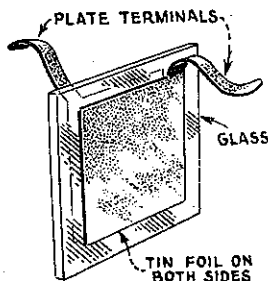


Figure 2

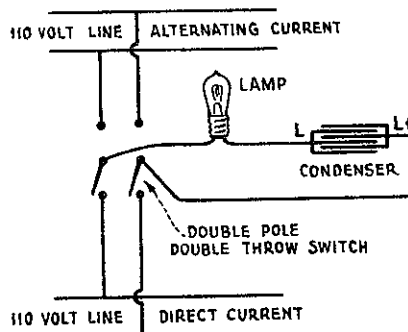


Figure 4

Suppose we conduct an experiment, the purpose of which will assist us to visualize the effect taking place when a condenser is placed in a direct current circuit and then in a circuit carrying alternating current. We will use a hook-up similar to the one used in conducting the experiment with inductance but, in place of the inductance, we

will insert a condenser as shown in Figure 4. Throw the double-pole double-throw switch down, thus connecting the circuit containing the condenser and lamp to the source of direct current. It is noticed that the lamp does not light. In a direct current circuit the condenser acts as an open circuit exactly as though you had opened the circuit by cutting the wire with a pair of pliers, and this experiment proves it, for otherwise the lamp would have given off light. In tracing the circuit, beginning at "L", you will find a connecting path for current as far as, and including, the plates but the intervening dielectric, which is an insulator, prevents current from flowing to "L1". An electromotive force does exist, however, and is available over the plates connected to "L" side of the line but steady current will not flow to the plates of the condenser connected to "L1" side of the line due to the intervening dielectric as was stated above. While the E.M.F. is rising to a maximum strength, it is changing in value and, during this time, a potential difference is built up on the opposite plates of the condenser. The lamp, if the capacity of the condenser and resistance of the lamp is correct, will become incandescent for a fraction of a second giving a flash of light but will not remain illuminated. If this occurred it would indicate that there was a momentary current flow after which the lamp ceased to glow.

Let us apply an alternating E.M.F. to the same circuit by throwing the switch up. The lamp at once burns at incandescence and remains in this state giving off light until the circuit is opened. While we could obtain a single flash of the lamp when a direct E.M.F. was applied, we find that by applying alternating current a continuous illumination results, proving without question that a condenser, when of the correct capacity in an A.C. circuit does not produce the effect of an open circuit as it did in the direct current circuit. There is an electrical phenomenon taking place in the space between the plates of the condenser. This space together with the condenser plates constitutes capacity. This space has the ability to receive and hold an electrical charge and is called the Dielectric. The plates of the condenser serve only the purpose of distributing the electromotive force over the dielectric.

The most common form of dielectric material is found in the shape of insulators. Air as a dielectric is frequently used, and it is from air that we base our standard for the "Specific Inductive Capacity" of the dielectric. Air, mica, glass, rubber, paper and oil all may be utilized to form a dielectric for the condenser. As air is taken as a standard it is given the value of unity, or 1. To explain this value of Specific Inductive Capacity, suppose we determine by measurement the amount of charge a condenser using air as the dielectric will accumulate with a definite E.M.F. Then under the same conditions we will measure the amount of charge in the same condenser using glass as the dielectric. It will be found that when glass is the dielectric medium the condenser will take a charge from 4.5 to 10 times as great as the condenser having air as the dielectric, this specific inductive capacity depending upon the grade of glass used.

SPECIFIC INDUCTIVE CAPACITY

The following table indicates the Specific Inductive Capacity of some of the most commonly used dielectrics.

Air	has a dielectric constant of	1.00
Castor oil	" " " "	4.67
Hard rubber	" " " "	2.5 to 3.50
Glass	" " " "	5.4 " 10.00
Mica	" " " "	4.0 " 8.00
Paper	" " " "	1.5 " 3.00

We find that when different insulating materials are placed between the plates of a condenser the capacity of the condenser will be changed.

To explain the charging action of the condenser it will be well for us to review briefly the subject of conductance, insulation, and a phase of the electron theory dealing with the atomic structure. The condenser circuit is composed of the conductor plates which are usually aluminum, tinfoil or copper.

The material selected as a conductor must have a low resistance, - in other words it should offer very little opposition to the movement of electrons which, as you know, produces what is termed an electric current.

Insulation is so named because of the opposition which it offers to the electronic movement and resulting electric current. Insulation in a direct current circuit produces the effect of an open circuit, but when the same insulation is used as a dielectric of a condenser and placed in an alternating current circuit it may have the effect of being a conductor, as you learned by the lamp and condenser experiment. The condenser does not permit an actual passage of current, - it has the effect of permitting a flow of current. This statement may, at first appear contradictory and somewhat confusing, but the effect of the conduction of alternating current through a condenser can be readily explained and made clear if we will but consider the nature of electric current flow as set forth in the electron theory.

According to the electron theory all bodies are considered to be made up of infinitesimally small particles of matter called Atoms and, revolving about the atom, much as the earth and other planets revolve about the sun, are much smaller particles called Electrons. The atom is considered to be made up of a charge of positive electricity and the electrons of charges of negative electricity. All bodies are made up of atoms and, since the atom is considered to constitute a positive charge of electricity and the electron negative electricity, all substances possess large quantities of electricity. We found in previous lessons that like charges repel and unlike charges attract. In nearly all cases, however, the positive electrical charge equals the negative electrical charge thereby neutralizing each other and from all outward appearances no electrical charges are evident. This

complete balance of positive and negative electricity may be upset and we then observe electrical effects.

The atom, being a force of positive electricity, attracts to it and holds a number of electrons of negative electricity in just the proper number to equal the positive force. There the electrons remain, revolving around the atom like the moons about Saturn in regular orbits and, with these two charges equal, the atom is said to be uncharged.

Negative electricity, or the electron, is considered to be the only form of motional electricity, therefore, if we can succeed in forcing an electron to leave the atom there will be less negative charge than positive, the system becomes unbalanced, and the atom predominates in positive charge. By returning the negative electron to the atom we again produce a balance and the atom is again neutral or uncharged. Now force an electron to the balanced atom; the atom now will have an excess of negative charge thus making it negative.

In a substance which is a good conductor of electricity, such as copper and some of the other metals, the electron can be moved easily from atom to atom and this is what takes place when an electromotive force is produced by either mechanical or chemical means. As all electrons are negative charges of electricity each electron caused to move from one atom to the next will cause an electron adjacent to it to be repelled with great force, and as long as the electromotive force is applied this repelling of electrons continues. It is this movement of electrons which results in what is called current flow.

In insulators, such as we employ as dielectric mediums of a condenser, the atom has a far greater attractive force for the electron and greater electromotive force is required to drive an electron from the atom.

Now suppose we have a condenser and a source of E.M.F., the limit of which is not great enough to completely dislodge or drive the electrons from the atom, but sufficiently great enough at its highest point to strain the electron from its normal position but not completely dislodging it from the atom, that is, to a position just short of the complete breaking away point. As the E.M.F. forces the electrons from the circuit into the dielectric, piling them in by the millions, the electrons about the atoms of the dielectric are displaced from their normal position giving away to the incoming electrons. It is this moving away of the electrons from their normal position about the atom that is called the displacement current, and the condenser is said to be charging, that is, charging in the sense that electrons continue, as a result of the E.M.F., to pile up in the dielectric. The position of the electrons that have been repelled has produced a strain on the whole structure of the atoms. This continues until a charge is stored up in the dielectric of the condenser. As the electrons move into the dielectric from the circuit they begin to create a counter E.M.F. opposing the applied E.M.F. and, when it equals the applied E.M.F., a further movement of electrons toward the dielectric cannot take place. The condenser is then said to be fully charged.

This action, so far, can be illustrated by imagining a tank of proper design used to store air. Let an air pump represent an electric generator and the particles of air the electrons. On starting the pump air at once is set in motion and is forced into the tank; the tank is under pressure and becomes strained. This strain caused by the piling up of air particles begins to exert a back pressure on the air being forced into the tank which continues to increase with every stroke of the pump until the stored up air reaches a pressure equal to that which the pump is capable of producing, at which point no more air will be forced into the tank. Now reduce the pressure of the air pump and the pressure which has been stored up in the tank will begin to discharge back into the pipe line.

A similar action takes place in the electric circuit. As the applied E.M.F. decreases in the alternating current circuit the strained dielectric is relieved, allowing the electrons to again assume their normal positions about the atoms. This reverse movement of the electrons produces a displacement current in the opposite direction and the condenser is discharging. As the applied E.M.F. reverses it distributes itself over the opposite plate of the condenser thus charging and straining the dielectric, this time opposite to the first charge and, as the alternating E.M.F. is constantly varying in strength and direction of flow, electrons are continually moving in and out of the

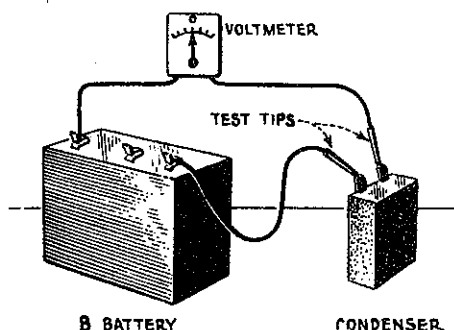


Figure 5

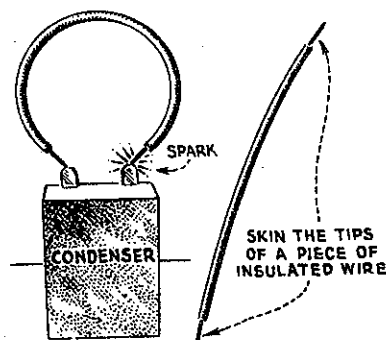


Figure 6

dielectric tending to keep the condenser plates at the right potential difference.

It is this movement of the electrons in and out of the dielectric which resulted in the current causing the lamp to glow in the experiment of Figure 3. It is therefore clear that the electrons do not actually pass through the dielectric from one plate to the other but simply move in and out of the dielectric, swinging through the circuit from one plate through the generator to the opposite plate. With this knowledge of the behavior of the condenser we are enabled to make an efficient test as to the worthiness of a condenser by using direct current for the test.

From a source of direct E.M.F., such as a 45 volt "B" battery, bring out two leads as suggested in Figure 5. Touch the terminals of the condenser and, at the same time, observe the voltmeter. The needle

will be deflected once and then return to zero. Remove the test tips and at once bring them in contact with the condenser a second time, - on the second contact there will be no deflection of the voltmeter needle. This proves, first, that the condenser is charged and, second, that it will not accept a further charge with the E.M.F. of 45 volts. Third, the current will not flow entirely through the dielectric.

Take a piece of insulated wire, skin the ends and short circuit the condenser as shown in Figure 6. When testing certain condensers in this manner a bright spark will result, proving that the dielectric held the charge until a path was offered to the charge to flow out, which it immediately did, its course being out of the dielectric into the plate which charged it, around the wire forming the circuit to the opposite plate, thus equalizing the charge until there was no difference of potential between the condenser plates.

Now secure a punctured condenser and follow the same procedure as before. The indicating needle of the meter will be deflected at every contact of the test tips indicating that the dielectric is broken down allowing current to flow directly through from one plate of the condenser to the other. A broken down condenser will not hold a charge.

A water analogy of the action of a condenser follows to illustrate displacement current. Refer to Figure 7. Here is a system of pipes "E" and "C", a tank divided into two divisions, "A" and "B", by a rubber partition "R". A reservoir is shown at "D" (the use of which will be explained later). On filling this system with water it is clearly seen that the water will be divided and prevented from moving by the rubber partition "R". There will be the same pressure in the half of the system B-C-D as in the half A-E-D, therefore there is no distortion of the rubber partition "R" and no movement of the water through the system. The conflicting arrangement of the arrows is intended to picture the water as idle, that is, no particular direction of motion being evident.

Figure 8 is the same arrangement but, in the reservoir "D", we have installed a centrifugal pump so designed that a continuous pressure is exerted on the water forcing it continually in one direction as long as the pump revolves. Revolving the pump in a clockwise direction the water will be forced into motion and will flow, as shown in Figure 8, from the reservoir "D" through pipe "E" and into "A" half of the tank. Now what happens? The water cannot move beyond the rubber partition but, due to the nature of the rubber, it will stretch and become distorted by the pressure of the water as shown and a displacement of water takes place.

We will assume that the pump has sufficient force to extend the partition to its limit but not enough to rupture it. The water in "B" half of the tank will be displaced in the half of the system B, C, D, by the forced distortion of the rubber partition, and will move towards reservoir "D". Now retain this: There has been a displacement

of water out of "B" through "C" to "D". Do not forget the word displacement because you will have to associate it with electronic movement later. Remember also that a stress has been placed against the rubber partition and, under this stress, it has been strained and, because of this strain, movement results in the rubber causing a displacement of the water in "B" half of the tank.

As the pump continues to revolve continuously in the same direction it maintains a stress upon the rubber partition and the rubber remains in a fixed strained position. As it cannot be strained further there is no further displacement of the water in "B" half of the tank when the partition has reached its limit of strain and, therefore, only one surge of water takes place in the B, C, D half of the system as long as the water is forced to move in the same direction.

This action is similar to the action of a condenser in a direct current circuit. There is actually one surge of displacement current through a condenser in a direct current circuit just as there was one surge of displaced water in Figure 8, but that completes it because the condenser dielectric is strained by the voltage displacing electrons sufficiently to cause one surge of current.

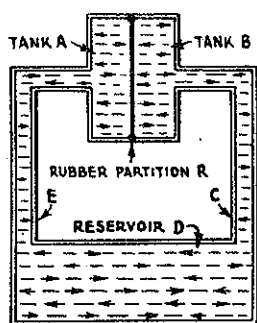


Figure 7

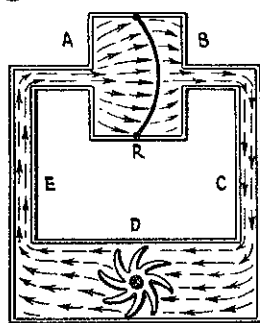


Figure 8

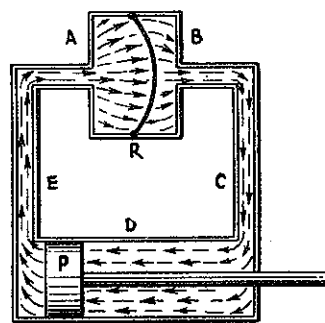


Figure 9

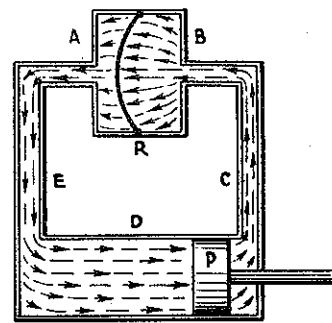


Figure 10

Explaining the water analogy for alternating current we will use Figure 9 which is the same type of arrangement as shown in Figures 7 and 8 but, instead of the centrifugal pump, we have a piston "P" which fits closely to the walls of the reservoir. Water fills the system as it did in Figure 7. It is clearly seen that if the piston "P" is moved to the left, Figure 9, it will exert a pressure on the water in the "EA" half of the system thus placing a stress on the rubber partition "R", causing it to stretch and a displacement of the water in "B" follows, which moves all the water in B, C, D. The elastic rubber partition is exerting a back pressure against the water forced against it by the piston and will, when the piston is moved to the right, give back to the A, E, D part of the system this stored up energy. Now move the piston to the right. At once the strain on the rubber is relieved and aids the piston in its movement by the fact of its tendency to straighten, thus forcing the water through A, E, D side of the system as shown in Figure 10. At the same time the piston has forced the water up through the pipe "C" into "B" half of the tank straining the partition this time to the left. The water in "A" half of the tank is displaced and movement takes place as shown by the arrows. With this arrangement and by a rapid back and forward movement of the piston water will move first in one direction then in the other, thus maintaining a flow of water which alternates in direction through the system.

CAPACITY

The capacity of a condenser is measured in terms of the farad and is a measure used to determine the relation between the amount of charge a condenser will hold and the E.M.F. strength to produce the charge. A condenser having a capacity of one farad is much too large for practical use, hence smaller condensers which are but fractional parts of a farad are used. In engineering practice, decimal parts are expressed as microfarads and micro-microfarads. Micro means "one millionth of" and micro-micro means "one millionth-millionth of". Hence, a condenser of one microfarad has a capacity of one millionth of a farad and a condenser of one micro-microfarad has a capacity of one millionth of a micro-farad.

The capacity of a condenser is sometimes expressed in centimeters, one centimeter of capacity being equal to 1.1124 micro-microfarads. This unit, however, is not so frequently used as the one explained in the foregoing paragraph.

GENERAL TYPES OF CONDENSERS

Condensers may be divided into four or five general types according to the dielectric used in their construction. The "Leyden jar" type was, at one time, a very common form of condenser used in transmitting equipment. It consists of a glass jar with walls about 1/8" thick coated inside and out to within two inches of the top with a tinfoil, copper or silver coating. This type is shown in Figure 11. The "Leyden jar" was one of the first types of electro-static condensers developed and, although it is quite efficient it has been rendered almost obsolete by more modern condensers incorporating higher efficiency and greater capacity in units of smaller physical dimensions.

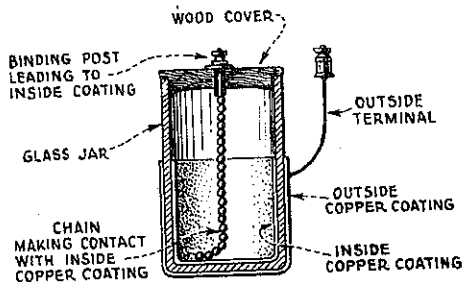


Figure 11

The Compressed Air condenser is a type that will be found in use in very few radio installations because expense in construction and upkeep does not warrant its general use. Briefly, the compressed air type is constructed as follows: A metal tank contains steel plates in which half of the plates are insulated from the tank and the other half connected to the tank. The tank is pumped to a pressure of 250 pounds providing a dielectric capable of withstanding a potential of 25,000 volts. Should a break-down potential be applied to this type of condenser no damage is done because the air simply fills in again making the dielectric perfect. This type of condenser is heavy, hard to handle and, in nearly all cases, trouble is experienced in maintaining the tank air tight.

The Glass Plate Condenser for use with high potentials is constructed as follows: Plate glass is used as the dielectric to which is glued tinfoil plates and, after being thoroughly dried, they are coated with shellac or hot paraffine. A single plate is shown in Figure 2.

A number of plates, depending upon the capacity desired, are connected together and immersed in an oil container as shown in Figure 12. This type of condenser is not used to any great extent due to the inconvenience of assembly and the time and work required in replacing broken plates in case of break down.

The foregoing types of condensers have been rendered obsolete, as far as modern radio practice is concerned, by the mica condenser. They have been mentioned because, at the period of their development, they represented the best practice in radio condenser construction.

The mica condenser uses sheet mica as the dielectric and the plates are made of tinfoil, or copper foil. Properly designed and constructed,

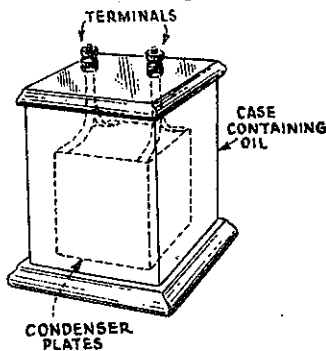


Figure 12

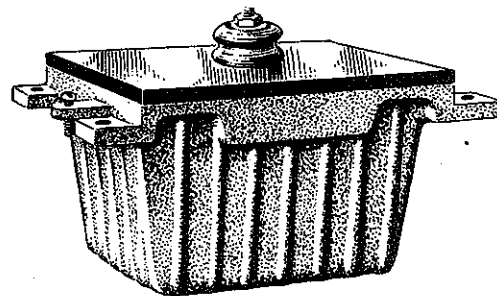


Figure 13

this condenser will withstand the high potentials encountered in radio transmitters, - its electrical efficiency is very good and large capacities may be secured within comparatively small physical dimensions. Furthermore, it is very sturdy as compared to the fragility of condensers employing glass as the dielectric, - such as the Leyden jar and the glass plate condensers.

A modern mica transmitting condenser is shown in Figure 13. The condenser is enclosed in an aluminum case, the space between the condenser and case being filled with an insulating compound to render the condenser moisture proof and to reduce brush discharges. The metal case is used as one terminal of the condenser while the other terminal is brought out to the binding post on the bakelite cover of the case.

CONDENSER GROUPING

Condensers are grouped to obtain various capacities and to perform certain functions. Certain circuits may call for condensers in series and others in parallel.

When condensers are connected in parallel, as shown in Figure 14, the total capacity resulting from such a connection is the sum of the individual capacities. In this instance, the different condensers in the group are shown as having capacity of .005 mf, .0005 mf, .001 mf and .0035 mf. The total capacity of such a parallel arrangement is, as stated, the sum of the individual capacities, or .01 mf.

Assume that the four condensers of Figure 15, C1, C2, C3, C4, have a capacity of .0025 each. What would be the total capacity when connected in series as shown in Figure 15? To obtain the total capacity of a number of condensers of equal value connected in series simply divide the capacity of one of the condensers by the total number of condensers in the circuit. Applying this rule to Figure 15 we obtain the answer, .000625 mfd., the total capacity of these four condensers when connected in series.

It becomes necessary under certain conditions, to employ condensers of different values in series. When this is the case the formula of reciprocals is required to solve for total capacity.

In Figure 16 we have four condensers C1, C2, C3, C4 connected in series. What is the total capacity? The formula for condensers connected in series is as follows

$$C = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \frac{1}{C_4}}$$

Substituting our known values as stated in Figure 16, the formula becomes

$$C = \frac{1}{\frac{1}{.001} + \frac{1}{.0005} + \frac{1}{.0025} + \frac{1}{.0001}}$$

$$= \frac{1}{\frac{1.000(1000.+ .0005)1.0000(2000. + .0025)1.0000(400.+ .0001)1.0000(1000}{1\ 000 \quad 1\ 0000 \quad 1\ 0000 \quad 1\ 0000}}$$

$$C = \frac{1}{1000.+ 2000.+ 400.+ 10000.} \quad C = \frac{1}{13,400}$$

$$C = \frac{13,400)1.0000000(.0000746}{\begin{array}{r} 93800 \\ 62000 \\ 53600 \\ 84000 \\ 80400 \\ 3600 \end{array}}$$

$$C = .0000746 \text{ mfd. (microfarads), or } C = 74.6 \text{ mmfd. (micro-microfarads).}$$

Capacity always consists of two or more opposing surfaces between which exists an insulating medium, (dielectric). This medium may be air, castor oil, hard rubber, glass, mica, paper or any insulating material. The capacity of a condenser is always found to vary depending upon the following facts.

(1st) Directly as the area of the opposing surfaces (which in this lesson would be the plates of the condenser).

(2nd) The ability of the dielectric to absorb a charge, i.e., the specific inductive capacity of the dielectric.

(3rd) Inversely as the separation of the opposing surfaces (plates).

This means that the area of the plates must be first calculated in square inches. The number of plates comprising the condenser must be known and the distance between the plates, i.e., the thickness of the dielectric.

Let us write the above as a formula: $C = \frac{A \times K \times 2248}{D \times 10^6}$

C = Capacity of the condenser in microfarads.

A = Total area of the plates in square inches.

K = Constant of specific inductive capacity.

D = The thickness of the dielectric, when solid dielectric is used, such as glass, etc., and the distance between the plates when air is used as a dielectric.

10 = A value found by experiments to be the correct number to use to multiply by "D" to give the result. (10" = 10,000,000,000.)

2248 is also a constant found by experiment.

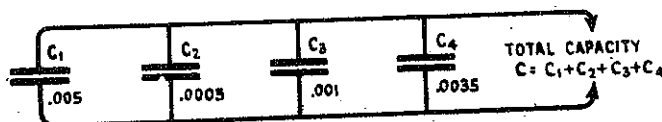


Figure 14

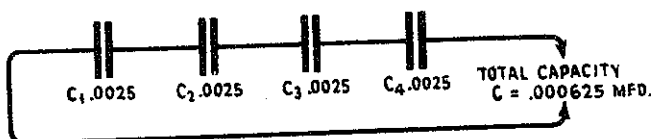


Figure 15

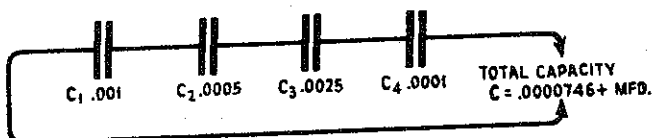


Figure 16

The area of the plates, the number of plates and distance between the plates can easily be found. The specific inductive capacity, or "K", however, must be determined by actual test and measurement when absolute accuracy is desired. When an approximation is desired a value of "K" may be used as given in specific inductive capacity tables. For example, suppose a condenser has a total plate area of 800 square inches. The dielectric is mica, one one-hundredth (1/100) of an inch in thickness. We now have all the necessary data from which to calculate the capacity of the condenser except the specific inductive capacity (dielectric constant "K")*. This can be obtained from tables giving the dielectric constant of different materials. Referring to the table given on sheet 3 we find the dielectric constant for mica varies from 4.0 to 8.0, depending upon the grade of mica.

Let us assume that the mica being used in this condenser has a dielectric constant of 5. Substituting these known values in the formula for capacity, the formula becomes

$$C = \frac{800 \times 5 \times 2248}{.01 \times 10,000,000,000}$$

$$C = \frac{8,992,000}{100,000,000}$$

$$C = .08992 \text{ mf}$$

CAPACITY REACTANCE

The effect of capacity in an alternating current circuit, termed capacity reactance, will now be considered. You will remember that, when inductance was introduced in an alternating current circuit, the effect produced was to retard or cause the current to lag the electromotive force. Capacity produces exactly the opposite effect, that is, the current leads the electromotive force.

Capacity reactance is expressed in ohms, as was inductive reactance, and is written X_c (X sub c) while inductive reactance is expressed X_L (X sub L).

Capacity effects exist between any two conductors when the electromotive force in one is a different potential than the other, with a dielectric between them. As you learned, air or any insulating substance is a dielectric, and there is always a possible capacity effect between two electrical conductors. If they are bare wires, air is the dielectric; if covered with insulation the insulation acts as a dielectric.

* (Note; specific inductive capacity (K) is more often termed the "dielectric constant".)

In bare wires running from pole to pole or, on a ship, from mast to mast, the air between the wires acts as a dielectric, the ground acting as one side, or plate, of a condenser while the wire is the other plate, and capacity exists there exactly as between two conductors running close to each other, or as in a condenser. Figure 17 gives an idea of capacity in circuits familiar to you.

In determining capacity it is seen that formulae for all conditions under which capacity exists would be rather a complicated work.

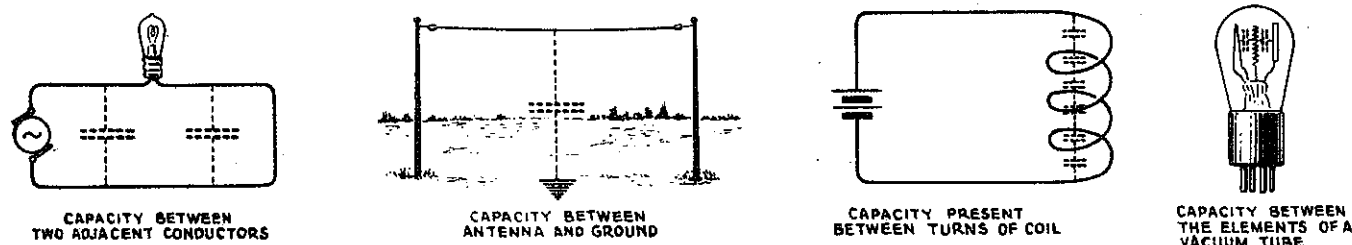


Figure 17

The capacity reactance in any circuit changes with a change in frequency and the greater the frequency the less effect will capacity reactance have on the circuit. An increase in frequency, when inductance is being considered, produced a greater inductive effect, therefore capacity acts to produce one effect, - that of opposing the E.M.F. when charging and, in a pure capacity circuit, the current is out of phase, leading the E.M.F. by 90 degrees, while inductance was out of phase oppositely, lagging the E.M.F. by 90 degrees. We worked out a problem in inductive reactance from a fundamental formula and we will now consider the formula for capacitive reactance.

The formula is as follows;- $X_c = \frac{1}{6.28fc}$

X_c = capacity reactance.

6.28 = 2π or 2×3.14 .

f = frequency.

C = capacity in farads.

In a 110 v., A.C. 60 cycle circuit, we have a .0025 farad condenser connected in series with the line. What is the capacity reactance?

By formula given: $X_c = 6.28 \times f \times C$

Substituting, $X_c = \frac{1}{6.28 \times 60 \times .0025}$

Multiplying the denominator

$$\begin{array}{r} 6.28 \\ 60 \\ \hline 376.80 \\ .0025 \\ \hline 188400 \\ 75360 \\ \hline .942000 \end{array}$$

then $X_c = \frac{1}{.942000}$

Dividing $.942000)1.0000000000(1.0615$

$$\begin{array}{r} 942000 \\ \hline 5800000 \\ 5652000 \\ \hline 1480000 \\ 942000 \\ \hline 5380000 \\ 4710000 \\ \hline \end{array}$$

We find that the capacitive reactance in the circuit as given above amounts to 1.0615 ohms.

Now let us increase the frequency to 500,000 cycles using the same condenser of .0025 farads. This will show us that, with an increase of frequency, the reactance is lowered.

Again by formula $X_c = \frac{1}{6.28 \times f \times C}$

Substitute $X_c = \frac{1}{6.28 \times 500,000 \times .0025}$

Multiplying the denominator

$$\begin{array}{r} 6.28 \\ 500000 \\ \hline 3140000.00 \\ .0025 \\ \hline 1570000000 \\ 628000000 \\ \hline 7850.000000 \end{array}$$

$7850)1.000000000(.00012738$

$$\begin{array}{r} 7850 \\ \hline 21500 \\ 15700 \\ \hline 58000 \\ 54950 \\ \hline 30500 \\ 23550 \\ \hline 69500 \\ 62800 \\ \hline 67000 \end{array}$$

or $X_c = .00012738$ ohms.

The purpose in working out this problem has been to show how according to the formula, capacitive reactance decreases with an increase in frequency. You found that, with a frequency of 60 cycles, a capacitive reactance of a little over one ohm reactance was present. When the frequency was increased to 500,000 cycles, however, the reactance was reduced to a fractional part of an ohm.

IMPEDANCE

Impedance, expressed in ohms, is the combined opposition in an A.C. circuit of the actual (ohmic) resistance and the apparent resistance, or opposition, due to the counter E.M.F. of self-induction and capacity.

The flow of alternating current is usually controlled by coils of high self-induction, known as reactance coils, or choking coils, which causes a reactive pressure in the circuit. This reactive pressure is termed inductive reactance and is expressed by formula as

$$X_L = 6.28 \times f \times L$$

When a condenser is connected in series in an A.C. circuit it acts as an effective resistance and exerts a back pressure on the charging E.M.F. This back pressure also opposes the reactive pressure set up by the choke coils. It is termed Capacitive reactance and is expressed by formula as

$$X_C = \frac{1}{6.28 \times f \times C}$$

The inductive reactance is often referred to as the positive reactance, and the capacitive reactance as the negative reactance.

When computing the total impedance of a circuit in which resistance, inductance and capacity is connected in series, the following formula is used.

$$Z = \sqrt{R^2 + \left[(6.28 \times f \times L) - \left(\frac{1}{6.28 \times f \times C} \right) \right]^2}$$

(Z is the symbol for impedance)

If we let X_L represent that part of the above formula written $6.28 \times f \times L$, and X_C that part which written

$$\frac{1}{6.28 \times f \times C}$$

we can then simplify the formula and express it as follows.

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

Let us assume that we have a circuit containing an inductance coil having a reactance of 10 ohms, a resistance (actual) of 16 ohms, and a condenser having a reactance of 4 ohms. Then by formula

$$Z = \sqrt{R^2 + (X_L - X_C)^2}$$

where Z = Impedance

R = Resistance (actual)

X_L = Inductive reactance in ohms.

X_C = Capacitive reactance in ohms.

Substituting the known values of 10 ohms, 16 ohms and 4 ohms respectively, we write:

$$Z = \sqrt{16^2 + (10 - 4)^2}$$

$$Z = \sqrt{16 \times 16 + (6)^2}$$

$$Z = \sqrt{256 + 6 \times 6}$$

$$Z = \sqrt{256 + 36}$$

$$Z = \sqrt{292}$$

$$Z = 17.08$$

17.08 is the total impedance in ohms of a circuit which contains 10 ohms inductive reactance, 16 ohms actual (ohmic) resistance, and 4 ohms capacitive reactance in series.

EXAMINATION - LESSON 15

1. What is a dielectric material?
2. Explain what happens when a condenser is placed in an A.C. circuit?
3. Describe a simple condenser.
4. What is capacitive reactance?
5. (a) Show by diagram how you would connect three condensers in series. (b) In parallel.
6. What is your understanding of the term "capacity"?
7. When three condensers, each having a capacity of .001 microfarads capacity, are connected in series what is the total capacity?
8. Describe three types of condensers.
9. What is the action of a condenser when placed in D.C. circuit?
10. When four condensers, each having a capacity of .002 microfarads capacity, are connected in parallel what is the total capacity?